Transport Processes in the Coastal Atmospheric Boundary Layer

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LONG-TERM GOALS

The long-term goals of this project are to better understand, and thus to be able to better predict, the transport of different constituents in the marine atmospheric boundary layer. This transport may be due to mesoscale flow systems at locations along mountainous coastlines or boundary layer processes at the coast. The transported constituents may be properties of the marine boundary layer, e.g. humidity, air pollution or aerosols, the latter both of natural and man-made origin. In particular I am interested in the cross-coast mixing potential. By this I mean the potential for finding properties from the marine environment inland or matter released over the continent end up in the marine environment.

OBJECTIVES

The dispersion and mixing of aerosols and other species in the coastal zone is influenced by meteorological processes on widely different space and time scales. The dispersion in itself is dependent on the local PBL turbulence structure, while on larger and longer scales the fate of constituents are determined by the mesoscale flow that arise from the very different surface forcing at the coast, dependent both on different surface types and the terrain-height ding the last few years. This includes data from the Swedish Baltic Sea coast, collected by the PI while working at the Department of Earth Sciences, Uppsala University, and from the US west coast, from the Coastal Waves 1996 project, collected by Drs David Rogers and Clive Dorman at the Scripps Institute of Oceanography, La Jolla, California. It has become clear that analysis of data such as this can be greatly augmented by the analysis of specific flow events using numerical models. Meteorological simulations of coastal flows have thus been performed with the Swedish MIUU mesoscale model, for coastal California (the PI and Dr Branko Grisogono, both at Stockholm University) and for Blekinge on the Swedish coast to the Baltic sea (the PI and MSc Ragothaman Sundararajan, at Uppsala University). In addition, the Penn State/NCAR MM5 mesoscale model was used to generate a data set of the entire June - August 1996 coastal California flow, coinciding with the Coastal Waves experiment (by Dr Darko Koracin at the Desert Research Institute (DRI), Reno, Nevada). We now have access also to this data base with MM5 simulations.

Several interesting mesoscale flows have been described, e.g. super-critical flow with expansion-fan dynamics, flows with a significant cross-shore flow and flows with interactions between PBL structure and boundary layer development. Flow realizations from model data will be used to both study specific events in detail and to generate a more global picture, e.g. using the MM5 data base. One tool to facilitate this is the LAP-model, a random-walk trajectory model developed at DRI. Full dispersion

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calculations with coupled dynamic models will also be utilized for case studies. In the latter, simplified but realistic source functions for e.g. marine aerosols will be used in numerical simulations to asess the transport mechansisms on time-scales from hours up to days. Some of this work will be performed using the Navy COAMPS numerical model, in collaboration with Dr Steven Burk, Naval Research Laboratory, Monterey, California.

WORK COMPLETED

A few cases with coastal flows from the Blekinge experiment in the Baltic Sea were simulated. The development of coastal blocking and the formation of a low-level jet was explained analyzing the data and by performing sensitivity simulations with the numerical model (Ragothaman and Tjernström 1999).

Several simulations for the Cape Mendocino area has been performed. In a first experiment, an actual case study of the flow on 7 June 1996 was accomplished (Tjernström and Grisogono 1999). In a later study, the forcing and the terrain were manipulated to elucidate important mechanisms (Tjernström 1999). Now, simplified terrain analogs are used to carry this study further in the mesoscale model (Söderberg and Tjernström 1999a; 1999b). Analysis of several flow types has also been performed directly using the data (Ström et al. 1999, Ström 1999a; 1999b).

The LAP-model, which is a so called "random-walk trajectory model" developed at DRI, was implemented in Sweden and a few cases from the MM5 data base of flows from summer 1996 has been studied (Ragothaman et al. 1999).

RESULTS

One day from the Blekinge coastal experiment in Sweden was simulated. Here the coastal flow encounters a heterogeneous coast line as the flow enters an open bay, with significant changes in coast line orientation relative to the flow. In the observations, this day is signified by the dissipation of a marine stratocumulus sheet, followed by a gradual collapse of the PBL offshore. Simultaneously, a low-level jet was observed to form, with a significant spatial character. The coastline irregular so that the eastern part of the southerly flow is relatively unaffected by land while the flow to the west enters an open bay, the Bay of Hanö. It was indicated that the jet structure was closely correlated with the structure of the terrain downstream of the measurements. The data was analyzed and it was concluded that the observed boundary layer had a turbulent structure that deviated significantly from the ideal homogeneous steady-state PBL that forms the basis for most model turbulence closures. However, the PBL statistics, expressed as profiles of normalized fluxes and variances, using time-local scaling parameters, were found to adhere more closely to the ideal state than the structure seemed to imply. This means that simplified closures can be used when modeling more complex boundary layers. Sensitivity simulations validated the hypothesized chain of events:

- The marine clouds dissolved partly under the influence of synoptic scale subsidence;
- The subsequent collapse of the PBL was also due to this subsidence;
- As the PBL collapses, it goes through a relatively rapid transition from a deep well-mixed state to a shallow sheared and statically stable state.

- Analysis of the turbulence data during this transition indicates that a turbulence closure that relies on a prognostic turbulent kinetic energy, but retrieves the turbulent fluxes from their steady-state equations are able to deal also with this non-stationary PBL;

- The transition is sufficiently rapid to trigger an inertial oscillation which is responsible for the jet formation. This mechanism is similar to the classical nocturnal jet, but can appear at any time of the day;

- Simultaneously, as the stability increases, the upstream terrain in the western part of the area starts to partly block the flow in a way that seems to be responsible for the spatial structure of the jet.

Data from the Coastal Waves 1996 project was analyzed, and it was concluded that the flow here is quite often supercritical. This results stems from the enforcement of a northerly along-coast jet that is strong enough to generate a supercritical flow, for typical PBL depths, in most cases. Only when the background flow is from the south is the northerly jet weakened to the extent that the flow becomes subcritical. Model simulations of the 7 June case shows a good agreement with the measurements and many sensitivity simulations were conducted to illustrate the main features of the flow. Main results are:

- The supercritical flow induces an expansion-fan south of Cape Mendocino, with a drastic reduction in PBL depth and an increased wind speed;

- The jet becomes detached from the local coast south of Cape Mendocino, which generates a region between the coast and the jet with a large curl of the surface wind-stress vector. An analysis of the observed SST shows that in Shelter Cove, south of the cape, this curl is responsible for the observed upwelling;

- The atmospheric flow is relatively insensitive to the effects of the upwelling. In runs with and without the observed SST depression downstream of Cape Mendocino, the model results are insignificantly different, thus there is little feedback between the ocean and the atmosphere for these conditions;

- The abrupt transition at Cape Mendocino is to a large degree determined by the cross-flow oriented terrain at the actual cape. This terrain causes two things to happen. a) In lee of the terrain a single buoyancy wave is excited, which is a main factor in controlling the collapse of the PBL inside of the expansion fan. b) The upstream flow is partially blocked by this terrain so that most of the flow acceleration occurs downstream of the cape;

- In simulations without the cape terrain, the flow starts to accelerate gradually even upstream of the coast, also when it is supercritical. The mechanism behind this is still not clear;

- Terrain height variations along the coast enhance the flow acceleration, when the terrain height is reduced along the flow direction.

Simulations with the LAP-model, using meteorological fields on selected days from the MM5 simulation of the summer of 1996, illustrates that there are situations when particles released over the ocean will remain in the marine environment for a long time. In other situations the flow causes the particles to cross into the San Jouaquin Valley very easily. Even in the latter conditions there is sometimes a “pile-up” of particles at certain locations, as e.g. in the Salinas River Valley.

IMPACT/APPLICATIONS

This project attempts to combine the study of small-scale atmospheric dynamics and the study of its impact on atmospheric transport. The dynamics part improve the understanding of the small-scale structure of coastal weather that are difficult to routinely forecast. For example, the apparent self-similarity of the Froude number patterns in supercritical flow past headlands may be used to interpret from courser model output for upstream conditions the appearance of local wind speed maximas. Also some properties of the coastal marine air, e.g. the presence of aerosol and low clouds, are detrimental to remote sensing based on electromagnetic radiation. A better understanding of processes that generate poor visibility conditions or the patterns of cloudiness and the possibility of such air to penetrate inland is useful in designing sensor systems of importance to the Navy. Also, better model predictions of such limitations can improve the desition-base for tactical desitions.

TRANSITIONS

These results has been utilized in the continued analysis of the data from in particular the Coastal Waves program. Comparisons with model results from COAMPS have prompted an active collaboration between this group in Sweden and NRL Monterey (Dr. Stephen Burk) and at Scripps in further analysing the turbulence structure (Dr. Ian Brooks) and comparing with extensive shallow-water model simulations (MSc Kate Edwards).

RELATED PROJECTS

This project has become an integral part of the Coastal Waves 1996 experiment, co-sponsored bu ONR and NSF. This project has also been closely linked to Swedish coastal atmosphere projects in relating local wind fields to the Swedish Wind Energy Program for offshore based “Wind Farms”. It forms the basis for a continued European Community sponsored program on the atmospheric transport and deposition of nutrients to the coastal ocean, MEAD (coordinator Dr Tim Jickells, University of East Anglia, and Dr Gary Geernaert, DMU in Denmark) as part of CAPMAN under the umbrella of Eurotrac-2.

PUBLICATIONS

Sundararajan, R., and M. Tjernström, 1999a: Observations and simulations of a non-stationary coastal atmospheric boundary layer. Quarterly Journal of the Royal Meteorological Society, in ptress.

Sundararajan, R., D. Koracin and M. Tjernström, 1999: Simulations of spatially-inhomogeneous marine intrusions along the US california coast during the warm season, 3rd Conference on Coastal atmospheric and Oceanic Prediction and Processes, New Orleans, 3-5 November.

Ström, L., 1999: Effects of coastal forcing on turbulence and boundary-layer structure, PhD thesis at the Department of Earth Sciences, Uppsala University, Sweden, ISBN 91-554-4557-8.

Ström, L., 1999a: Across-coast variability of the marine atmospheric boundarly layer off Califirnia, Journal of Geophysocal Resrearch, submitted.

Ström, L., 1999b: Observeations of surface-layer turbulence in the marine atmospheric boundary-layer off the California coast, Journal of Geophysocal Resrearch, submitted.

Ström, L., M. Tjernström and D.P. Rogers, 1999: Observed dynamics of coastal flows at Cape Mendocino during Coastal Waves 1996, Journal of the Atmospheric Sciences, submitted.

Söderberg, S., 1999: Supercritical coastal flows: Hypothetical scenarios, MSc thesis at the Department of Earth Sciences, Uppsala University, Sweden.

Söderberg, S, and M. Tjernström: Numerical investigations of coastal supercritical flows: Hypothetical scenarios, 3rd Conference on Coastal atmospheric and Oceanic Prediction and Processes, New Orleans, 3-5 November.

Tjernström, M. 1999: Sensitivity of coastal atmospheric supercritical flow to ambient conditions. Tellus, in press

Tjernström, M., and B. Grisogono, 1999: Simulations of supercritical flow around points and capes in the coastal atmosphere. Journal of the Atmospheric Sciences, Journal of Atmospheric Sciences, in press.

Tjernström, M., and R. Sundararajan, 1999b: Observations and modeling of a non-stationary coastal boundary layer, 3rd Conference on Coastal atmospheric and Oceanic Prediction and Processes, New Orleans, 3-5 November.